Balancing of intermittent renewable power generation by demand response and thermal energy storage

Energy Systems Conference, London, 15 June 2016

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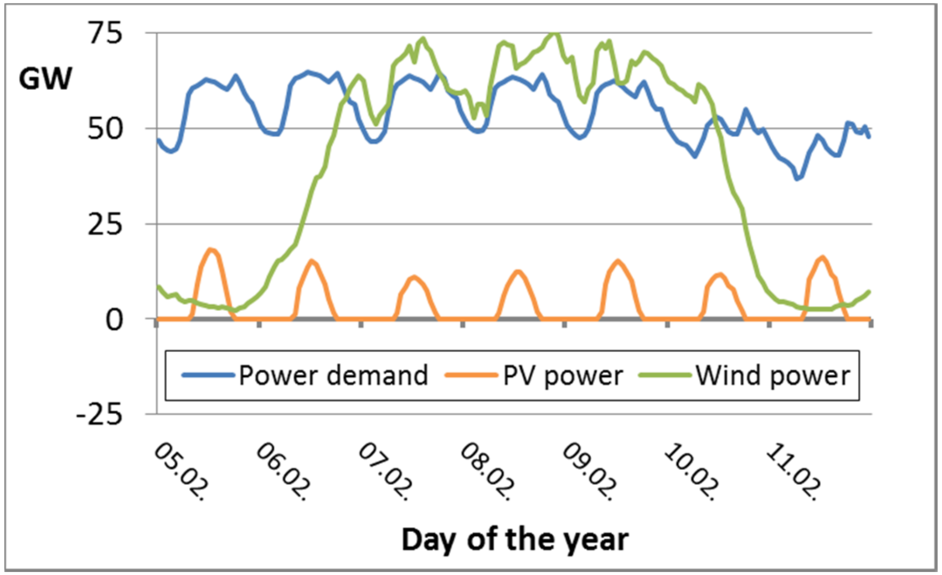
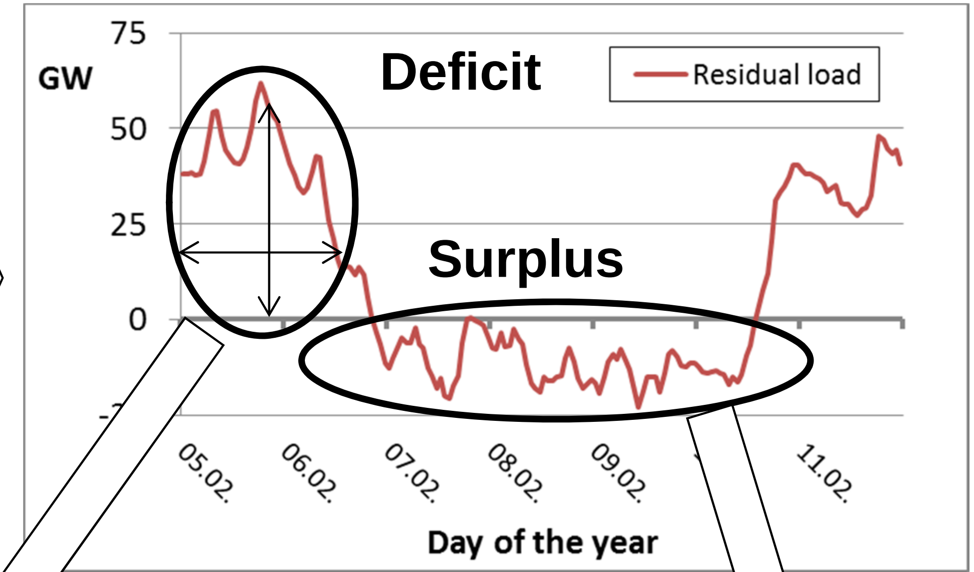
DLR

Research focus: VRE based power supply systems





Load balancing options

Coverage of deficits

- Adjustable power plants
- Storage discharging
- Power demand reduction
- Electricity import

Utilization of surpluses

- Storage charging
- Usage in other demand sectors
- Power demand increase
- Electricity export

Research questions

- To what extent can demand response (DR) and thermal energy storage (TES) contribute to a mostly renewable power supply in Germany?
- Are DR and TES competitive with other storage options?

Methodology

Quantification of theoretical demand response potentials

Methodology described in Gils, H. C. Assessment of the theoretical demand response potential in Europe. Energy , 2014, 67, 1 - 18

- Installed capacities of flexible loads
- Hourly potential for load reduction
- Hourly potential for load increase

Analysis of CHP potentials in district heating and industry

Methodology described in: Gils, H. C. et al. GIS-based assessment of the district heating potential in the USA. Energy , 2013, 58, 318 - 329

- Maximum CHP supply shares
- Regional allocation of CHP

Enhancement of the REMix energy system model

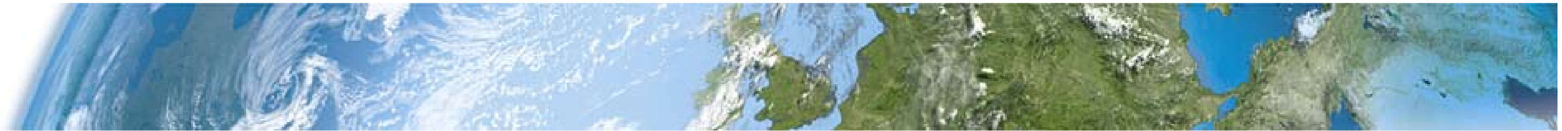
Gils, H. C. Economic potential for future demand response in Germany – Modeling approach and case study. Applied Energy, 2016, 162, 401 - 415

- Modelling of load shifting/shedding
- Modelling of the heating sector

Economic assessment of DR and energy sector linkage

Gils, H. C. Balancing of intermittent renewable power generation by demand response and thermal energy storage, University of Stuttgart, 2015

- Investment in DR and TES
- Impact on VRE integration
- Interaction with alternatives



REMix modelling approach

Input

Climate and weather data, techno-economic technology parameter, scenario data

REMix Energy System Model

Energy Data Analysis Tool *REMix-EnDAT*

high-resolution RE technology potentials, hourly profiles of demand and RE generation, potentials for CHP and DR

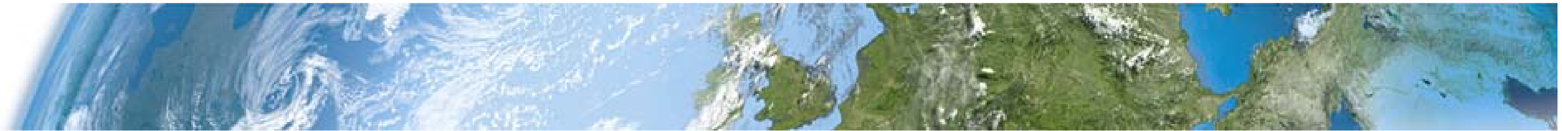
Energy System Optimization Model *REMix-OptiMo*

Least-cost composition and hourly operation of the power system, determined by linear optimization, Minimization of system costs: $C_{system} = \sum c_j x_j$

Output

Hourly system operation, system costs, CO_2 emissions, construction of new assets

- Deterministic linear optimization model realized in GAMS
- Assessment of investment and hourly system dispatch during one year



REMix case study on DR and TES usage in Germany – approach

- Scenario analysis for the year 2050
  - Predefined power plant park based on scenario studies
  - Predefined heating supply structure, including CHP and electric heat pumps
  - Endogenous gas turbine capacity expansion to avoid supply shortfalls
- Focus on the analysis of the balancing of VRE fluctuations
  - Comparison of systems with/without DR and power-controlled heat supply
  - Endogenous investment in DR, thermal storage and electric boilers
  - Impact on back-up capacity demand, system operation, costs and emissions
- Consideration of Germany as part of a European network

REMix case study on DR and TES usage in Germany – scenarios for the year 2050

Reduced balancing demand

H_2T	Hydrogen usage in the transport sector Production in **flexible electrolysis**
CSP	**Import of dispatchable RE electricity** from CSP Reduced wind and PV capacities in Germany
Grid	Endogenous **grid capacity expansion**
Base	Base scenario, peak load 88 GW, electricity demand 522 TWh VRE capacities: PV 76 GW, wind onshore 55 GW, offshore 35 GW
Wind	**Increased wind onshore capacity,** reduced wind offshore
PV	**Increased PV capacity,** reduced wind offshore

Increased balancing demand

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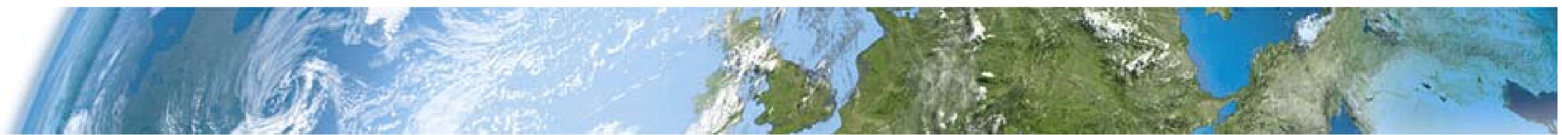
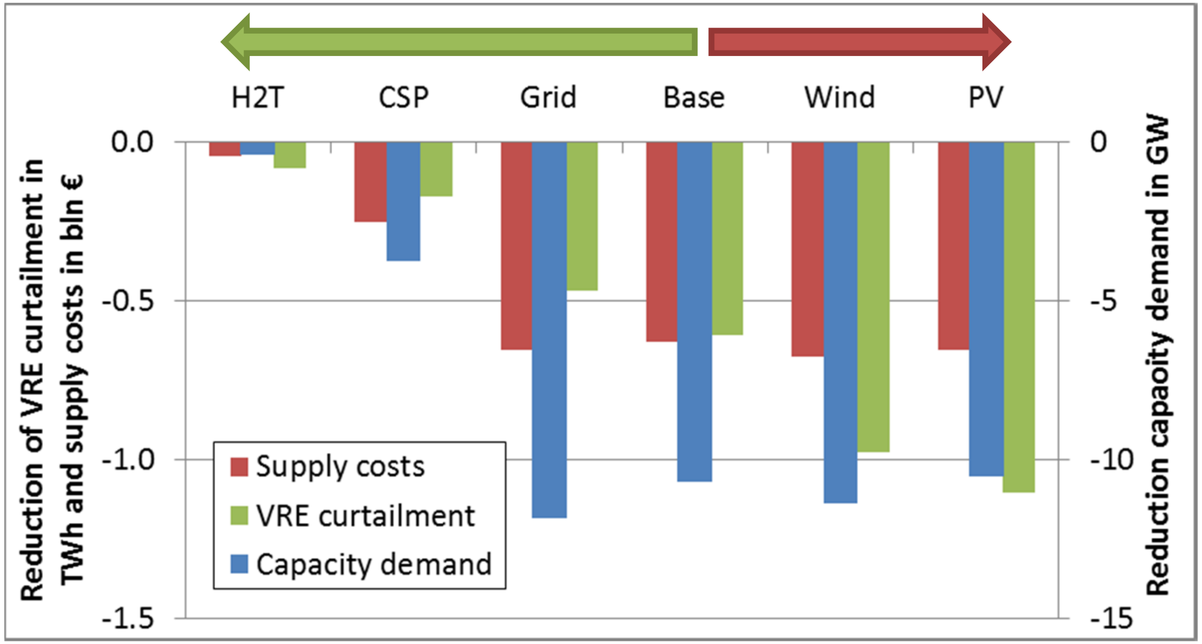


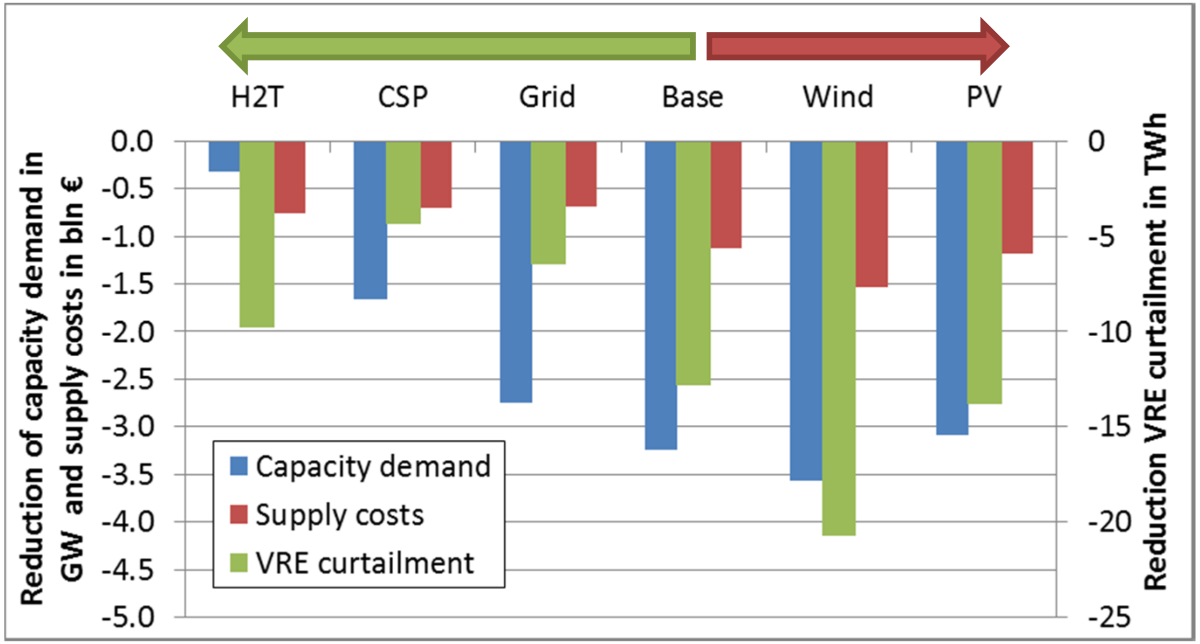
REMix results: demand response benefits



H2T – H_2 vehicles
CSP – CSP import
Grid – grid expansion
Base – Reference
Wind – additional onshore wind
PV – additional PV

- DR increases with PV share and is reduced by flexible electrolysis and CSP
- Application of DR mostly limited to short time peak shaving of the residual load
- w/o DR: system costs 26-28 bln €, curtailment 10-40 TWh, back-up 4-24 GW
- Reductions achieved: costs 0.7 bln €, curtailment 1.1 TWh, back-up 12 GW

REMix results: thermal energy storage benefits



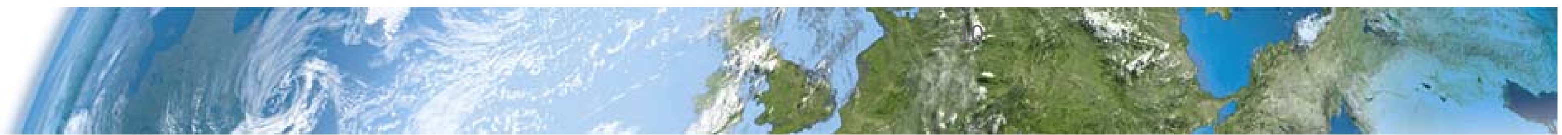
H2T – H_2 vehicles
CSP – CSP import
Grid – grid expansion
Base – Reference
Wind – additional onshore wind
PV – additional PV

- Reduction of curtailment particularly related to wind power share and grid availability
- Achieved by modified CHP/HP operation enabled by TES and electric heating
- w/o TES: system costs 26-28 bln €, curtailment 10-40 TWh, back-up 4-24 GW
- Reductions achieved: costs 1.5 bln €, curtailment 21 TWh, back-up 3.6 GW

Further insights and conclusion

- Focus of DR is on provision of power, not energy
  - ➢ Additional DR potential in industry should be tapped
- Power-controlled heat supply is an effective measure to increase RE integration
  - ➢ TES should be deployed hand-in-hand with VRE power generation
  - ➢ Electric heat production from VRE generation peaks has high potential
- DR and power-controlled heat supply can reduce costs and emissions
  - ➢ Both are important elements in a future energy system mainly relying on VRE
- DR and power-controlled heat supply are complementary measures

- Balancing strongly related to generation structure and available technologies
- Usage on smaller temporal and spatial scales not assessed
- Methodology tends to underestimate the potentials



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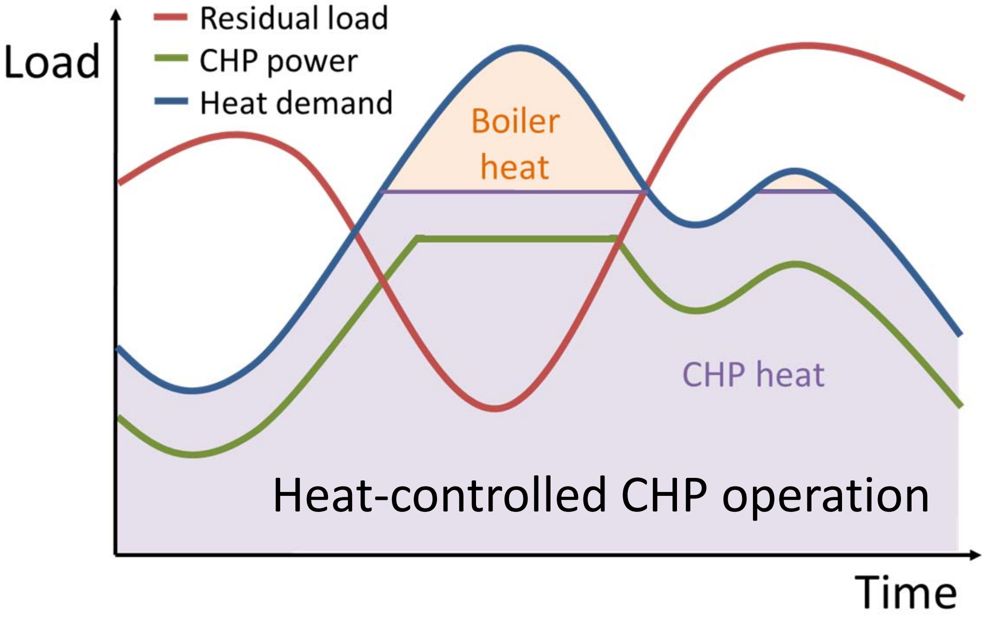
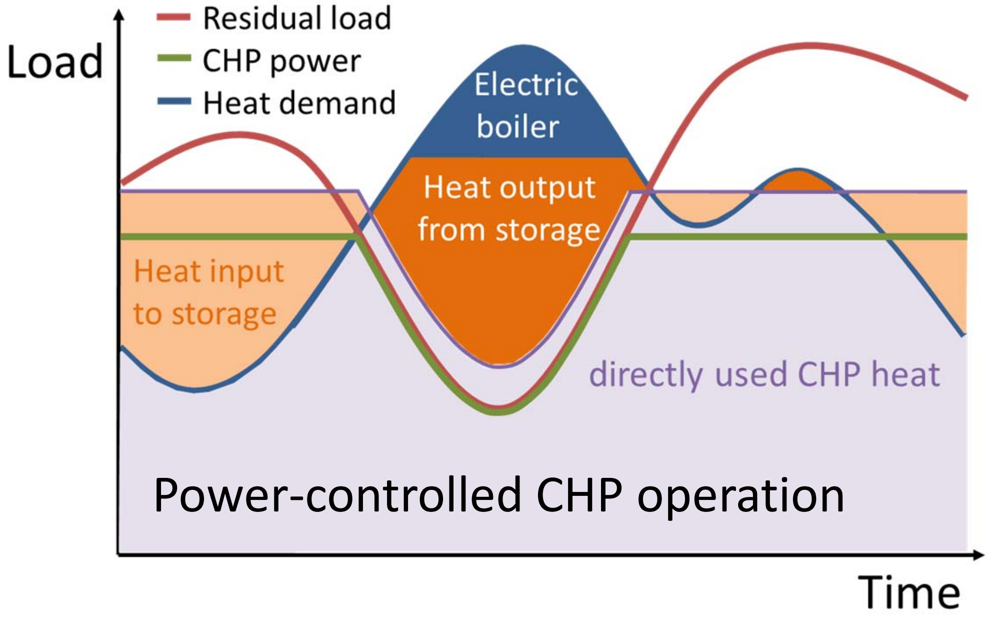
Enhanced coupling between electricity and heat sector



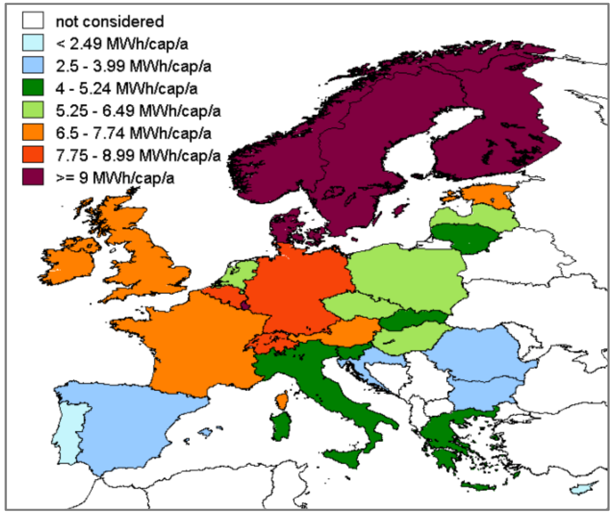


- Thermal storage (TES) allows for modified CHP and heat pump operation
- Electric boiler in CHP supply can use surplus power from VRE
- Impact on capacity demand, curtailments and costs are assessed for Germany

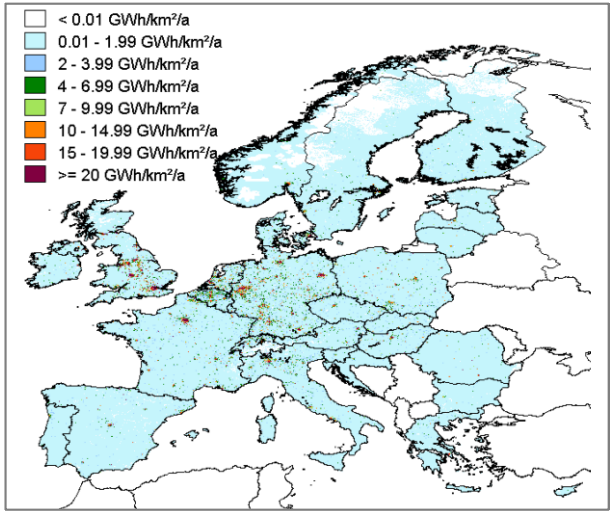
Gils, H. C. Balancing of intermittent renewable power generation by demand response and thermal energy storage, PhD thesis, University of Stuttgart, 2015

Technical potentials of district heating

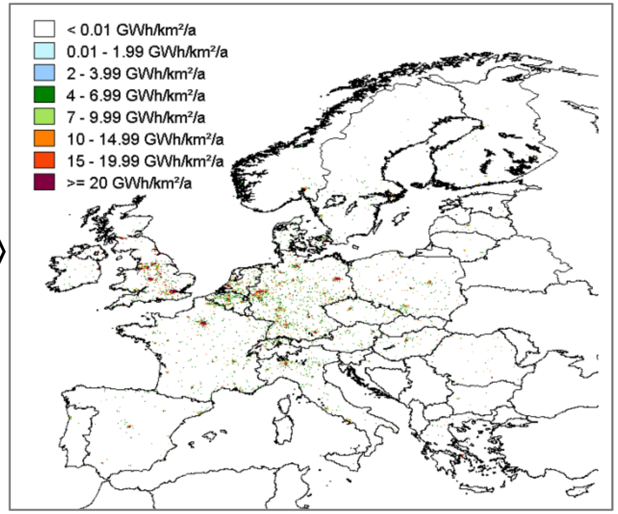
Specific Demand



Demand Density



District Heat Areas



- GIS-based assessment of heat demand densities
- Quantification of technical DH potentials in a spatial resolution < 1 km²

⇨ More than half of the demand can be supplied by CHP

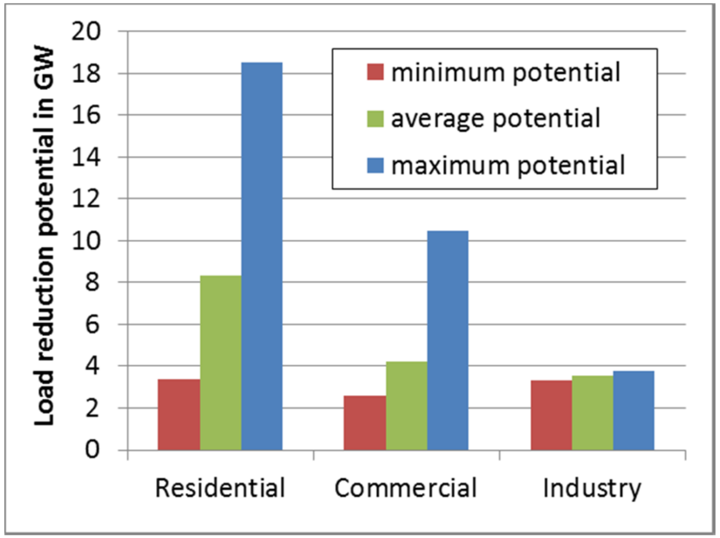
Methodology described in: Gils, H. C. et al. GIS-based assessment of the district heating potential in the USA. Energy , 2013, 58, 318 - 329

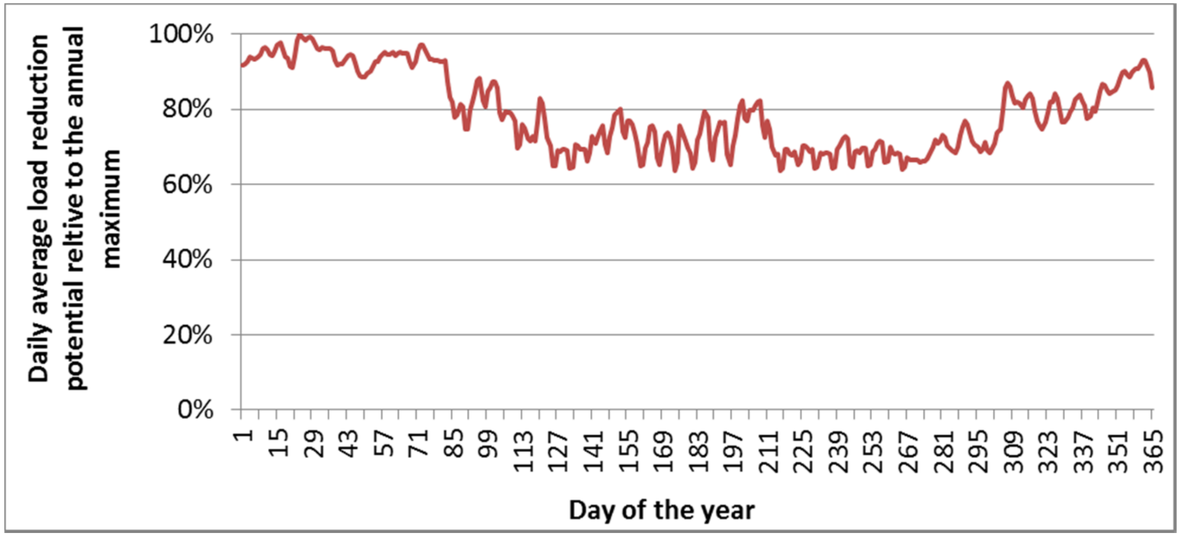
Theoretical demand response potential

- Annual electricity demand
- Representative load profile
- Availability for DR
- Capacity utilization

- Installed capacities of flexible loads
- Hourly potential for load reduction
- Hourly potential for load increase

Annual averages for Germany: 14 GW load reduction, 32 GW load increase





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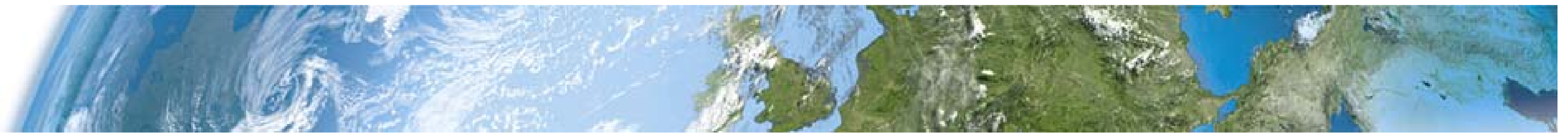
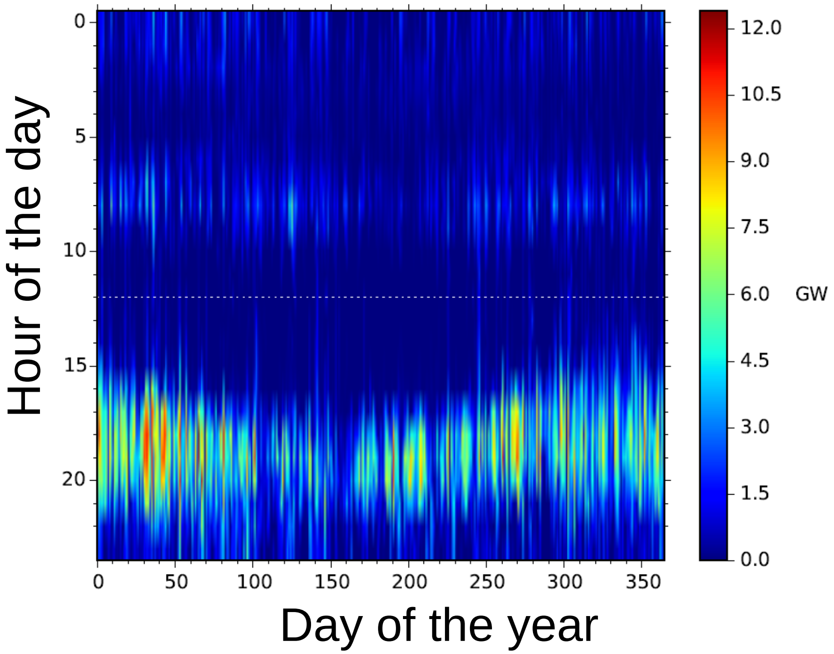
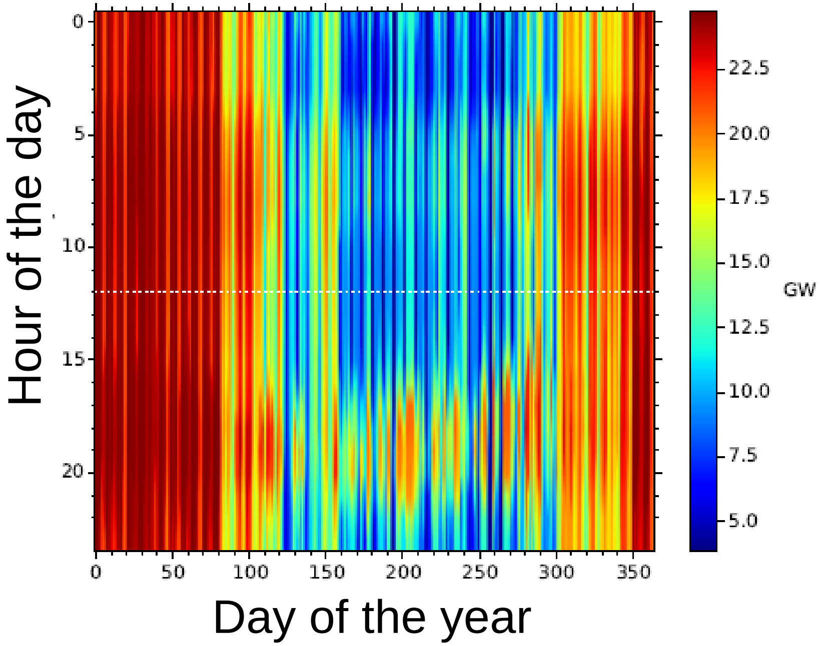


Hourly Operation of DR and CHP

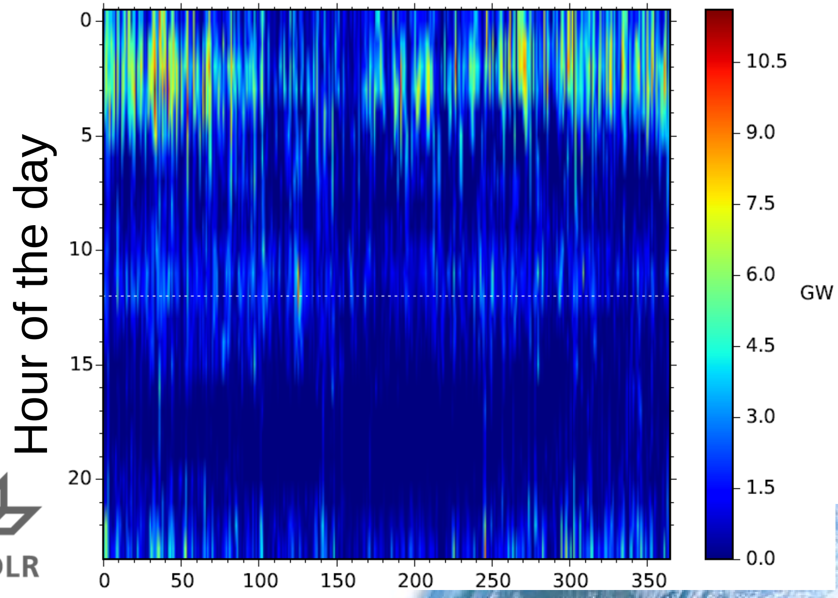
Load reduction



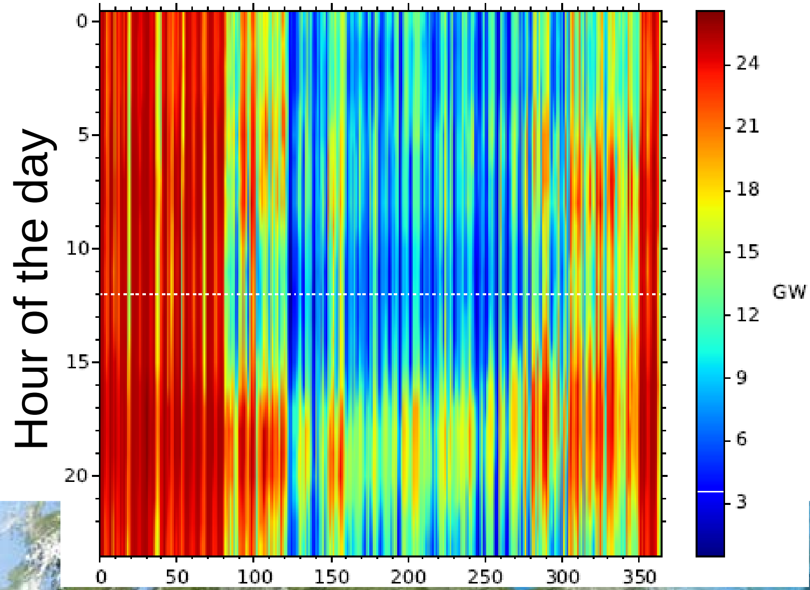
Heat-controlled CHP operation



Load increase



Power-controlled CHP operation



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